US009858719B2

(12) **United States Patent**
Dorner et al.

(10) **Patent No.: US 9,858,719 B2**
(45) **Date of Patent: Jan. 2, 2018**

(54) **BLENDED REALITY SYSTEMS AND METHODS**

(71) Applicant: **Amazon Technologies, Inc.**, Seattle, WA (US)

(72) Inventors: **Charles Shearer Dorner**, Seattle, WA (US); **Paul Barnhart Sayre, III**, Gig Harbor, WA (US); **William R. Hazlewood**, Seattle, WA (US)

(73) Assignee: **Amazon Technologies, Inc.**, Seattle, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 268 days.

(21) Appl. No.: **14/673,533**

(22) Filed: **Mar. 30, 2015**

(65) **Prior Publication Data**

US 2016/0292917 A1 Oct. 6, 2016

(51) **Int. Cl.**

G06T 15/50	(2011.01)
G06T 19/00	(2011.01)
G03B 21/20	(2006.01)
G02B 27/01	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***G06T 19/006*** (2013.01); ***G02B 27/01*** (2013.01); ***G02B 27/026*** (2013.01); ***G03B 21/2053*** (2013.01); ***G03B 21/2066*** (2013.01); ***G06T 7/70*** (2017.01); ***G06T 15/50*** (2013.01); *G02B 2027/014* (2013.01); *G02B 2027/0138* (2013.01); *G06T 2207/10004* (2013.01); *G06T 2207/30201* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,507,570 A	4/1970	Bourdier et al.
5,639,151 A	6/1997	McNelley et al.
6,257,727 B1	7/2001	Melville

(Continued)

FOREIGN PATENT DOCUMENTS

DE	19943355	3/2001
JP	2010070889	4/2010
WO	WO 2014/100250	6/2014

OTHER PUBLICATIONS

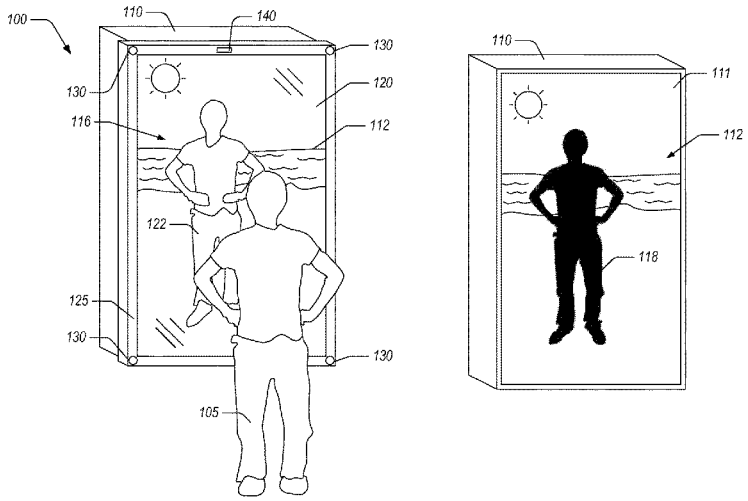
PCT Search Report and Written Opinion for Application No. PCT/US2016/024335 dated Jun. 14, 2016 in 15 pages.

Primary Examiner — Zhengxi Liu
Assistant Examiner — Khoa Vu
(74) *Attorney, Agent, or Firm* — Knobbe Martens Olson & Bear LLP

(57) **ABSTRACT**

Systems and methods are provided for generating a blended reality view to a user, the blended reality view combining images reflected by a mirror with images transmitted from a screen behind the mirror. Systems for generating blended reality views can include a display device with a screen positioned behind a mirror. The display device can generate a pattern of illumination and non-illumination on the screen so that the illuminated portions of the screen substantially transmit through the mirror. Projectors can be used to illuminate objects in front of the mirror so that the illuminated objects are reflected by the mirror. In combination, the portions of the screen transmitted through the mirror and the illuminated objects reflected by the mirror can provide a blended reality view to a user viewing the mirror.

20 Claims, 10 Drawing Sheets



(51) **Int. Cl.**
G02B 27/02 (2006.01)
G06T 7/70 (2017.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,481,851	B1	11/2002	McNelley et al.	
6,578,962	B1	6/2003	Amir et al.	
6,999,649	B1	2/2006	Chen et al.	
7,144,113	B2	12/2006	Fujikawa et al.	
7,197,165	B2	3/2007	Ryan	
7,307,675	B2	12/2007	Abileah	
7,883,212	B2	2/2011	O'Connell et al.	
8,172,400	B2	5/2012	O'Connell et al.	
8,262,226	B2	9/2012	LaDuke et al.	
8,326,025	B2	12/2012	Boughorbel	
8,408,706	B2	4/2013	Yahav	
8,462,192	B2	6/2013	O'Connell	
8,493,496	B2	7/2013	Freedman et al.	
8,594,425	B2	11/2013	Gurman et al.	
8,649,025	B2	2/2014	Teodorescu	
8,692,738	B2	4/2014	Smithwick et al.	
8,717,417	B2	5/2014	Sali et al.	
8,744,121	B2	6/2014	Polzin et al.	
8,857,994	B2	10/2014	Smithwick	
2003/0214459	A1	11/2003	Nishihara et al.	
2005/0018140	A1*	1/2005	Ishizaki	A45D 44/005 353/28
2007/0288332	A1	12/2007	Naito	
2008/0174704	A1*	7/2008	Tan	H04N 9/3147 348/745
2010/0302138	A1	12/2010	Poot et al.	
2011/0210970	A1	9/2011	Segawa	
2012/0044335	A1*	2/2012	Goto	A45D 44/005 348/77
2012/0229592	A1*	9/2012	White	H04N 7/15 348/14.08
2013/0100240	A1*	4/2013	Liu	H04N 7/144 348/14.08
2013/0202161	A1	8/2013	Shor et al.	
2013/0283208	A1*	10/2013	Bychkov	G06F 3/017 715/810
2015/0279113	A1*	10/2015	Knorr	G06T 19/006 345/633

* cited by examiner

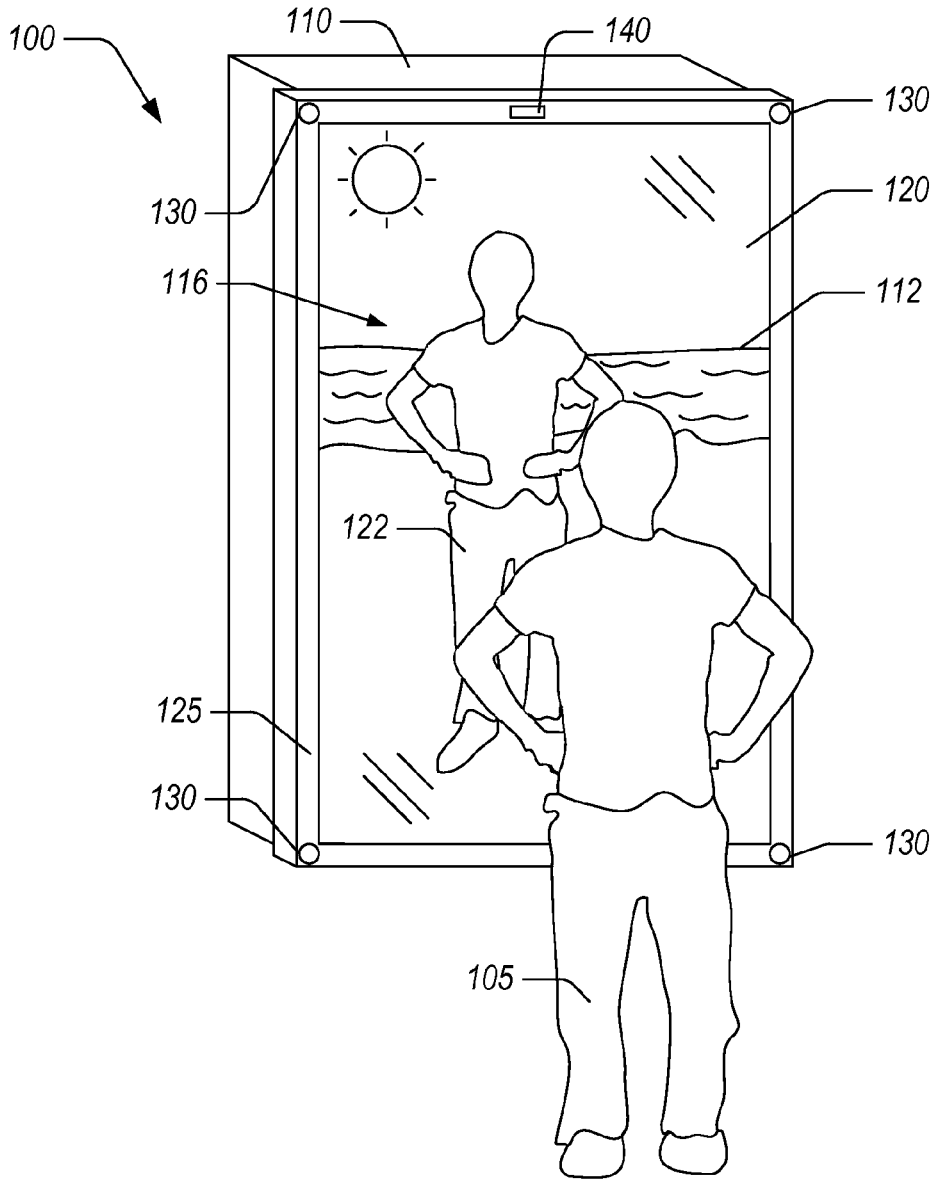


FIG. 1A

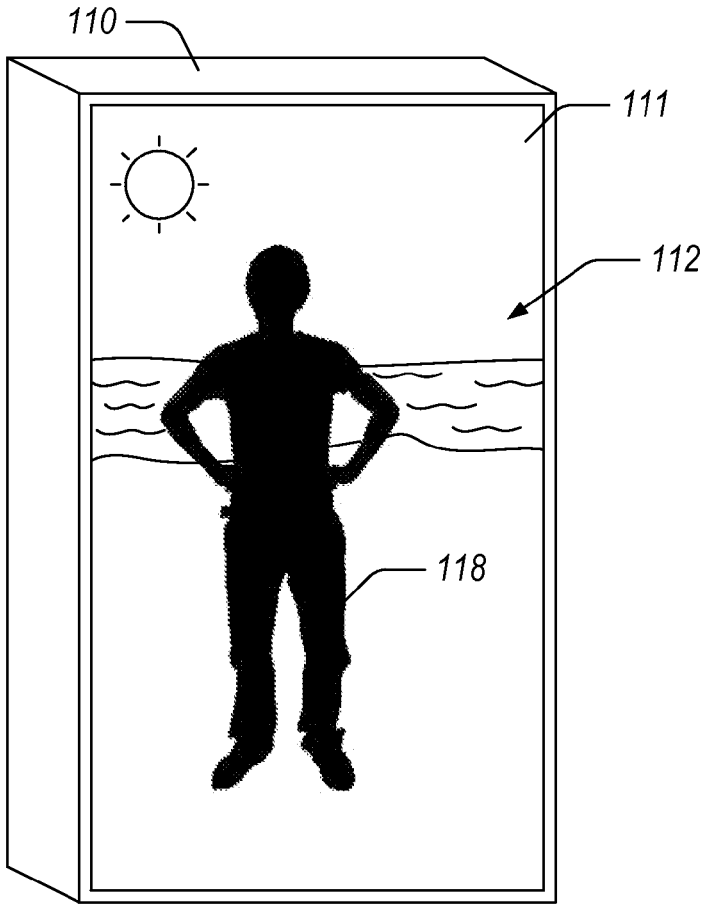


FIG. 1B

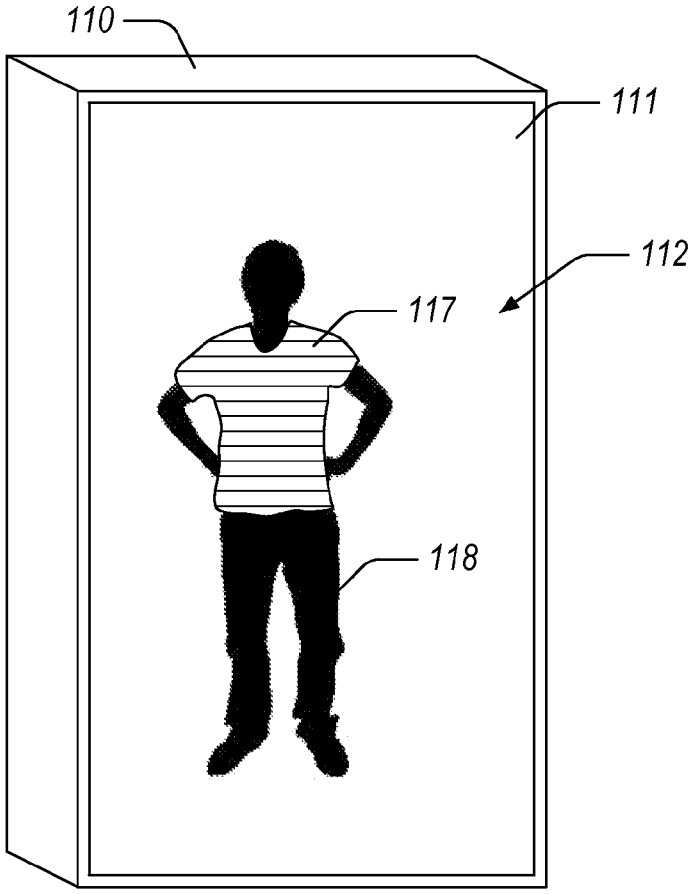


FIG. 1C

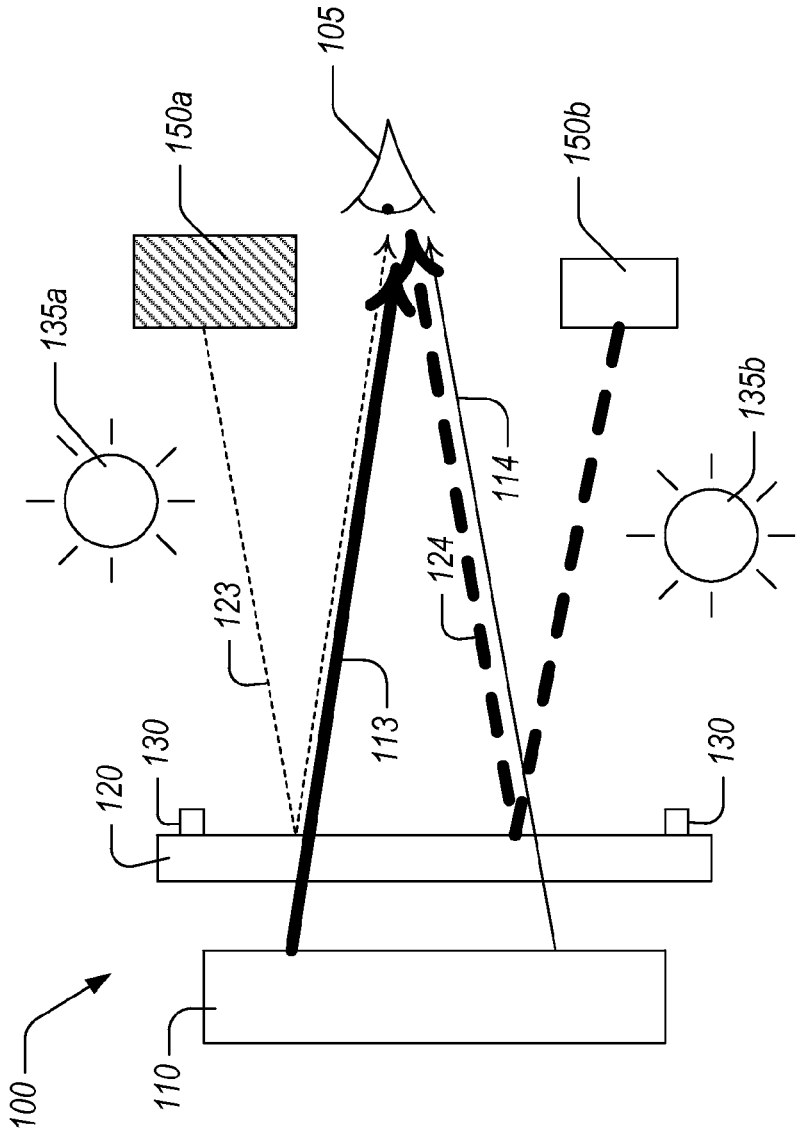


FIG. 2

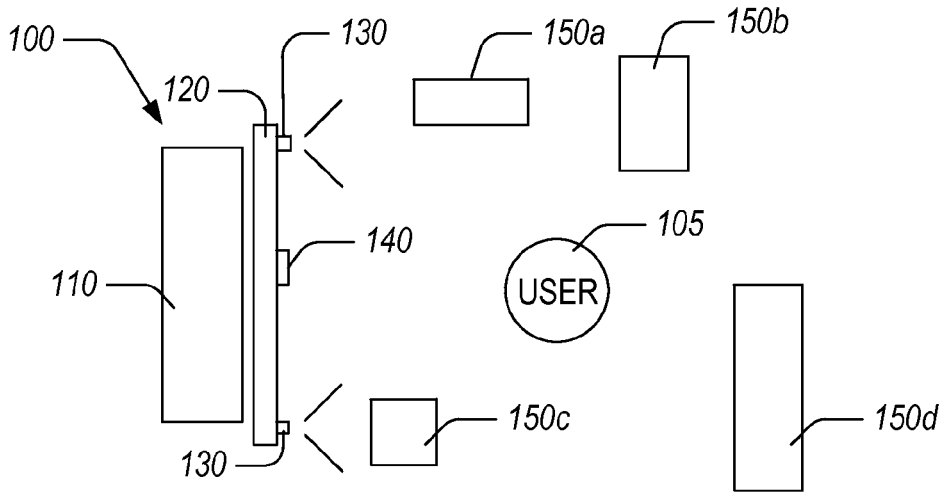

100
120
130
150a
150b
140
105
USER
110
150c
150d
130

FIG. 3A

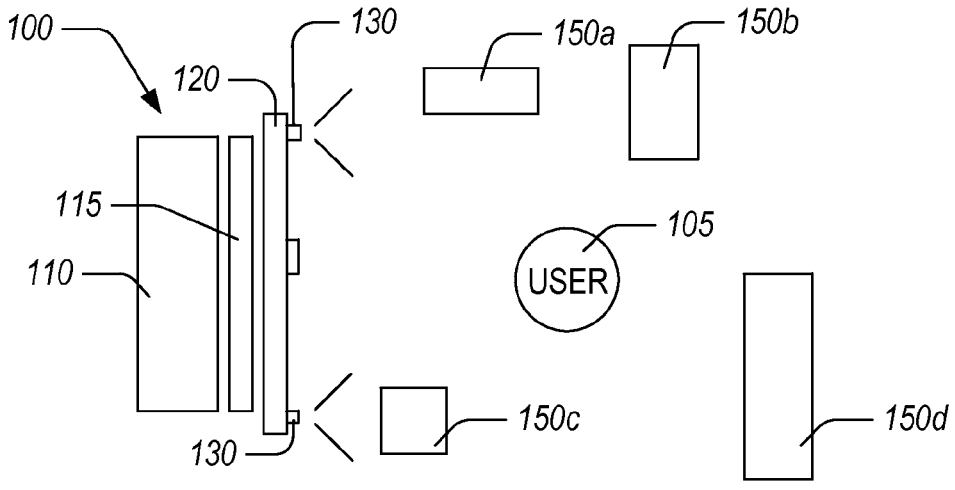

100
120
130
150a
150b
115
105
USER
110
150c
150d
130

FIG. 3B

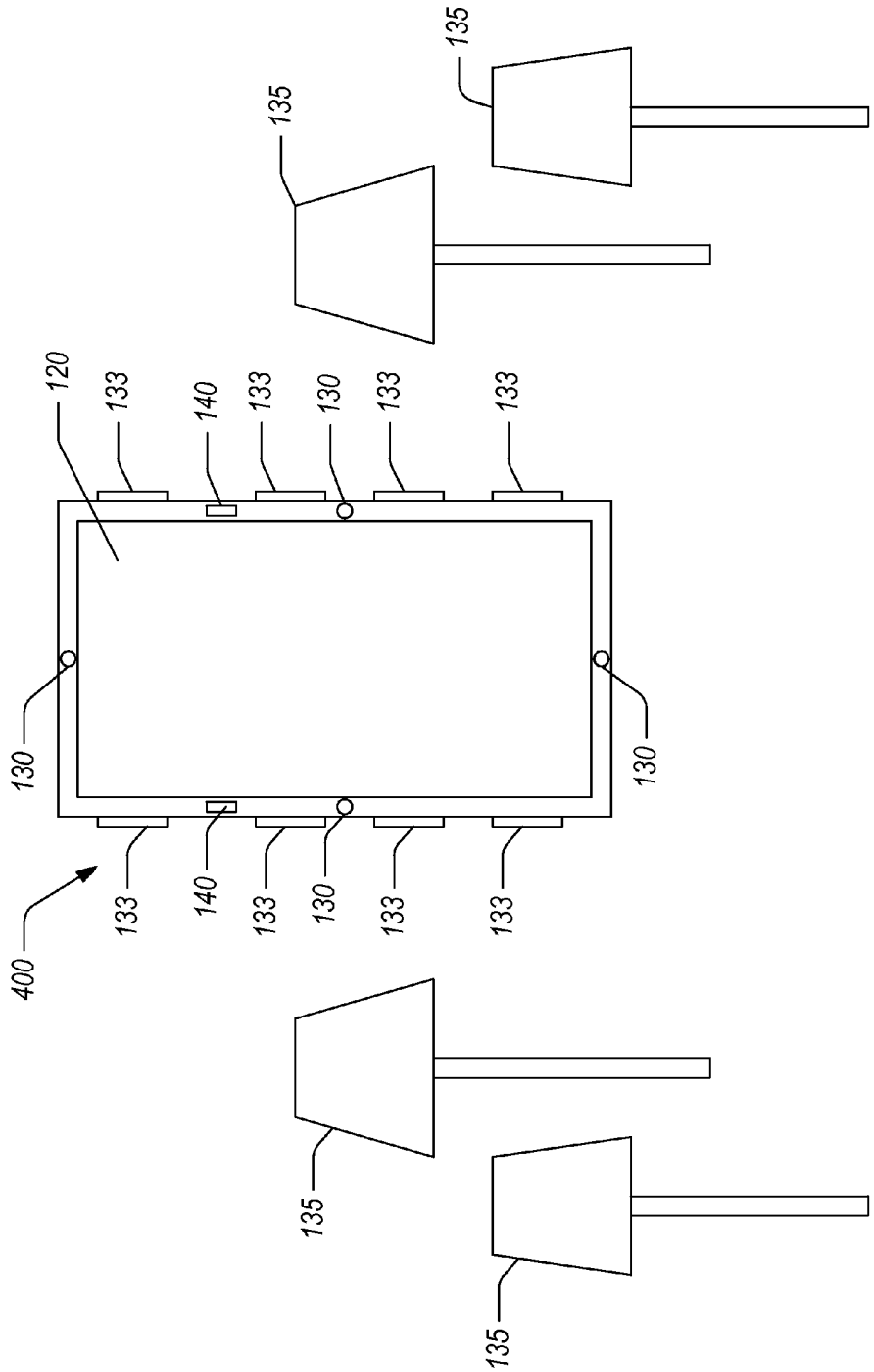

135
135
120
133
140
133
130
133
133
130
130
133
140
133
130
133
133
400
135
135

FIG. 4

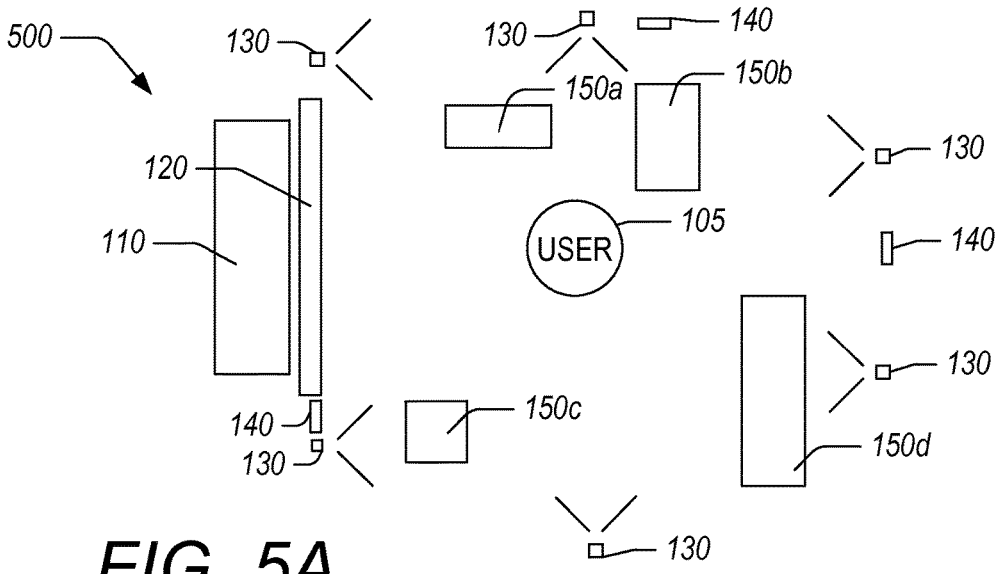

500
130
130
140
150a
150b
120
130
110
USER
105
140
130
150c
140
130
150d
130

FIG. 5A

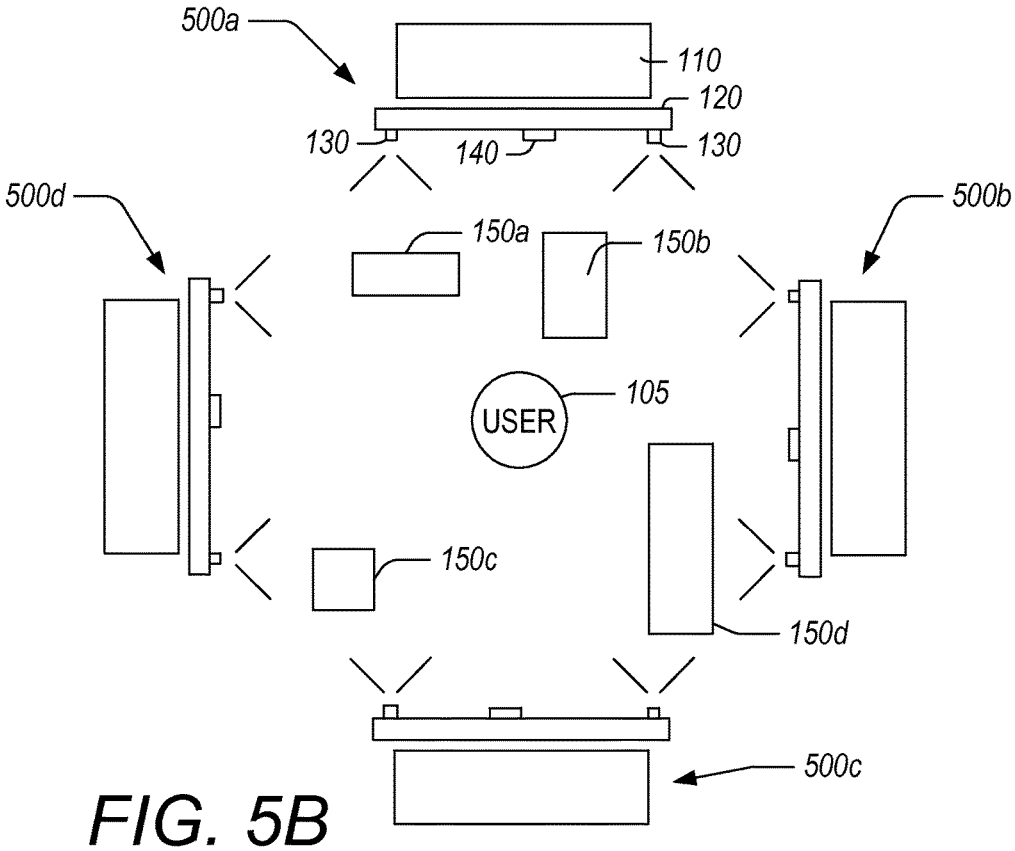

500a
110
120
130
140
130
500d
500b
150a
150b
USER
105
150c
150d
500c

FIG. 5B

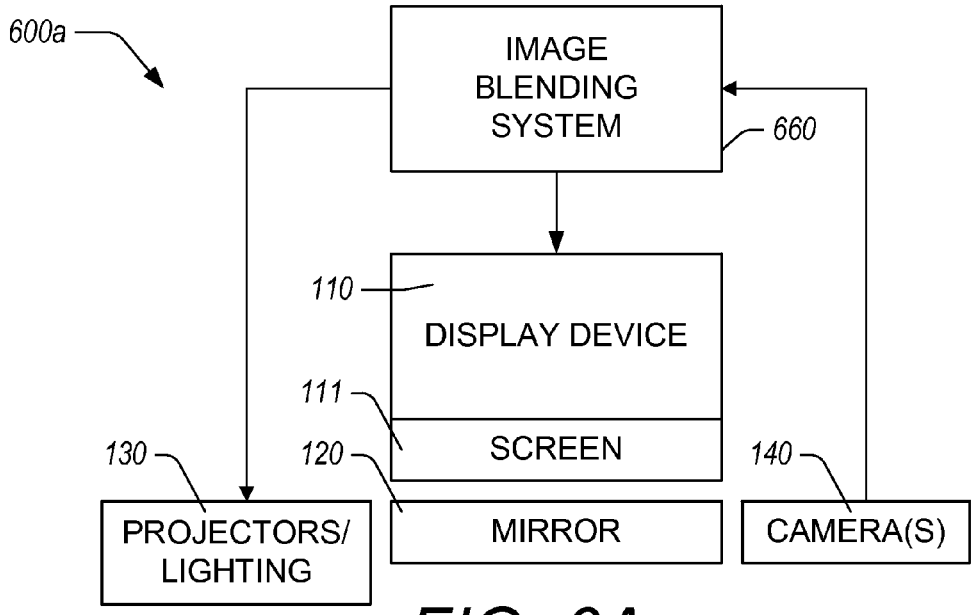

600a
IMAGE BLENDING SYSTEM
660
110
DISPLAY DEVICE
111
SCREEN
130
120
140
PROJECTORS/ LIGHTING
MIRROR
CAMERA(S)

FIG. 6A

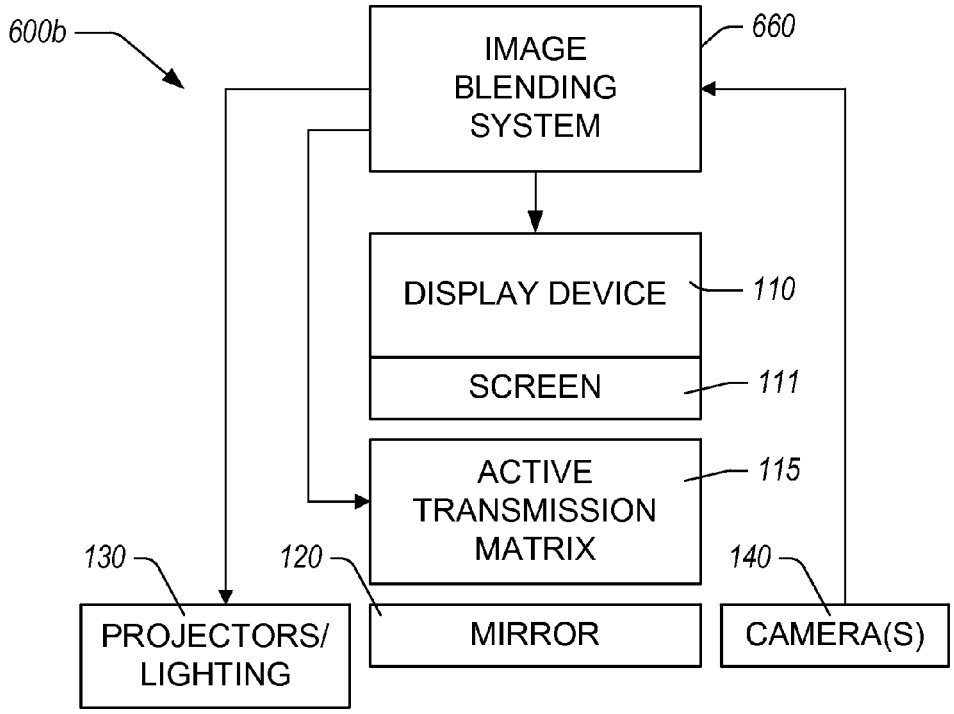

600b
IMAGE BLENDING SYSTEM
660
DISPLAY DEVICE
110
SCREEN
111
ACTIVE TRANSMISSION MATRIX
115
130
120
140
PROJECTORS/ LIGHTING
MIRROR
CAMERA(S)

FIG. 6B

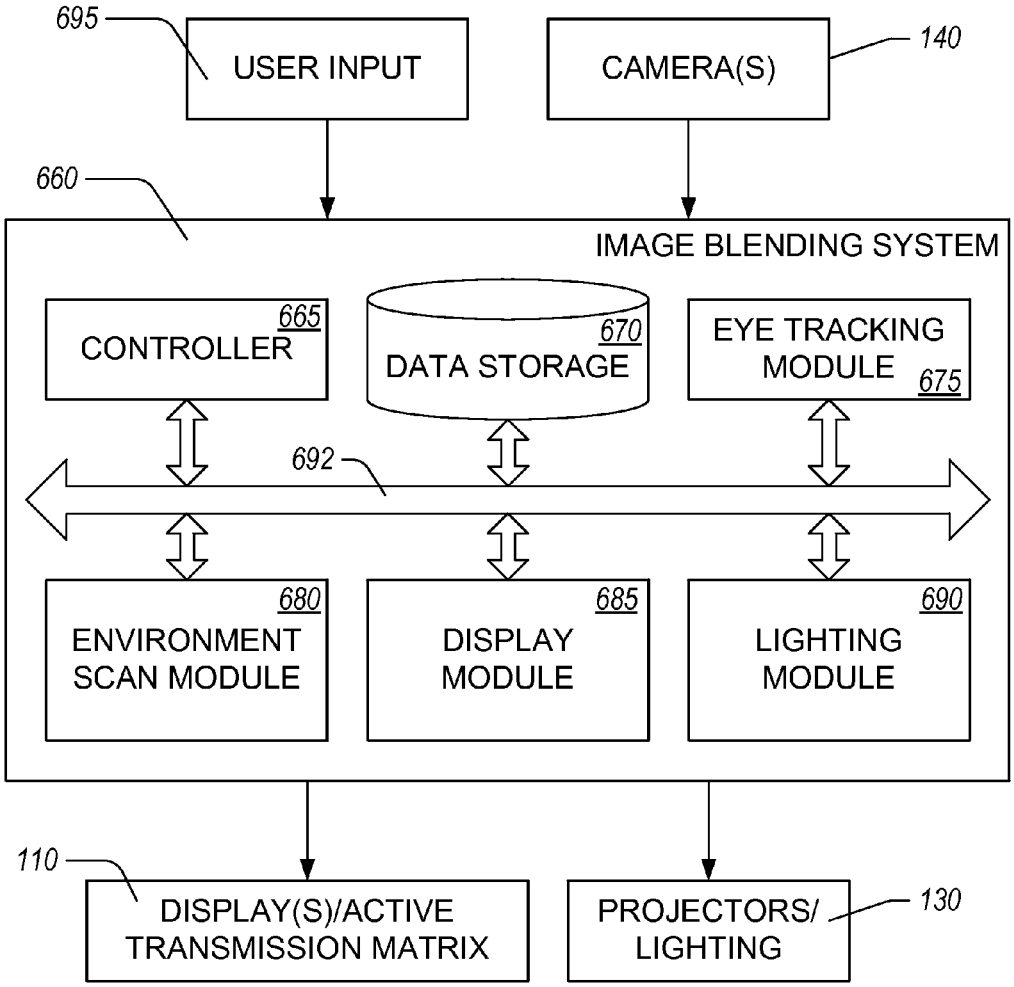

695
USER INPUT
CAMERA(S)
140
660
IMAGE BLENDING SYSTEM
665
CONTROLLER
670
DATA STORAGE
EYE TRACKING MODULE
675
692
680
ENVIRONMENT SCAN MODULE
685
DISPLAY MODULE
690
LIGHTING MODULE
110
DISPLAY(S)/ACTIVE TRANSMISSION MATRIX
PROJECTORS/ LIGHTING
130

FIG. 7

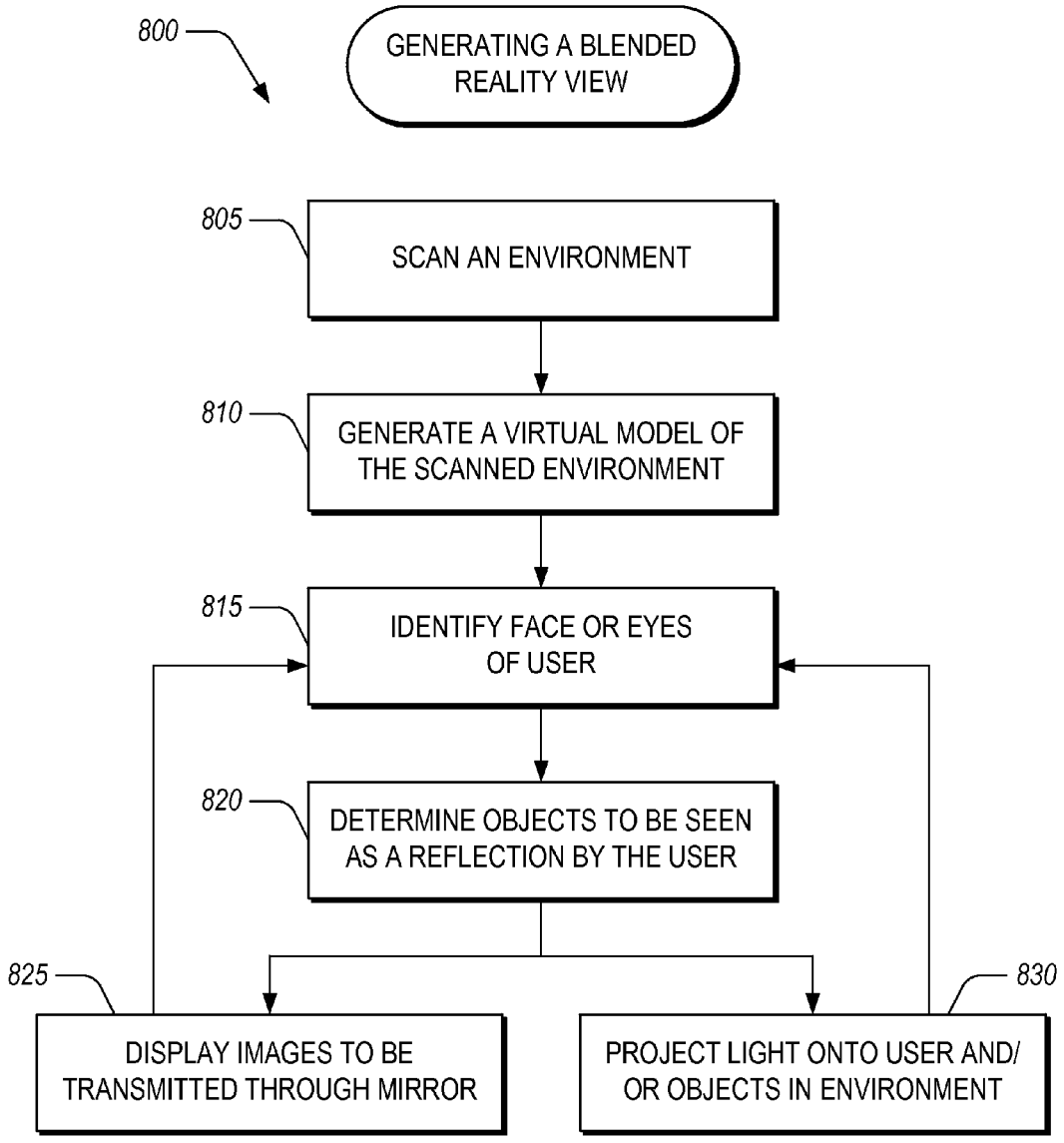

800
GENERATING A BLENDED REALITY VIEW
805
SCAN AN ENVIRONMENT
810
GENERATE A VIRTUAL MODEL OF THE SCANNED ENVIRONMENT
815
IDENTIFY FACE OR EYES OF USER
820
DETERMINE OBJECTS TO BE SEEN AS A REFLECTION BY THE USER
825
DISPLAY IMAGES TO BE TRANSMITTED THROUGH MIRROR
830
PROJECT LIGHT ONTO USER AND/ OR OBJECTS IN ENVIRONMENT

FIG. 8

BLENDED REALITY SYSTEMS AND METHODS

BACKGROUND

For entertainment and other purposes, unique visual displays can enhance the experiences of users. These visual displays can be used to alter scenes as perceived by users, for example, by adding objects to the scene that do not actually exist. One method of providing such a visual display uses an illusionary technique referred to as "Pepper's ghost" that can produce a virtual object in a scene as a latent or ghost-like image. This illusionary technique uses glass angled relative to a viewer, a display or object out of direct view of a viewer, and tailored lighting schemes. However, such techniques are significantly limited, requiring space that extends beyond a visual display or that significantly increase the size of a visual display. In addition, these techniques can produce unrealistic results as the virtual objects placed in the scene are generally translucent and low contrast.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects and advantages of the embodiments provided herein are described with reference to the following detailed description in conjunction with the accompanying drawings. Throughout the drawings, reference numbers may be re-used to indicate correspondence between referenced elements. The drawings are provided to illustrate example embodiments described herein and are not intended to limit the scope of the disclosure.

FIG. **1**A illustrates an example blended reality apparatus configured to generate a blended reality view.

FIGS. **1**B and **1**C illustrate a display of the example blended reality apparatus of FIG. **1**A.

FIG. **2** illustrates a diagram of a user simultaneously perceiving reflected light and transmitted light, wherein the respective intensities of the reflected and transmitted light are controlled by a blended reality apparatus.

FIG. **3**A illustrates a top view of an example blended reality apparatus, wherein the apparatus includes a plurality of projectors configured to selectively illuminate objects within an environment in front of the mirror.

FIG. **3**B illustrates a top view of an example blended reality apparatus, the apparatus including an active transmission matrix between a display and a mirror.

FIG. **4** illustrates an example apparatus configured to generate a blended reality view, the apparatus configured to control lighting within an environment to enhance the blended reality view.

FIG. **5**A illustrates a top view of an example apparatus for generating a blended reality view, the apparatus including projectors and cameras positioned around and within an environment in front of a mirror.

FIG. **5**B illustrates a top view of a blended reality system comprising a plurality of blended reality apparatuses, each blended reality apparatus configured to generate a blended reality view.

FIGS. **6**A and **6**B illustrate functional block diagrams of example blended reality systems comprising an image blending system.

FIG. **7** illustrates a functional block diagram of an example imaging blending system.

FIG. **8** illustrates an example method for generating a blended reality view.

DETAILED DESCRIPTION

Generally described, aspects of the present disclosure relate to generating a blended reality view for a user by combining reflections from a mirror with light transmitted through the mirror by a display. The present disclosure includes systems and methods configured to blend transmitted and reflected light to form a single scene, as perceived by a user, by controlling the amount of light on either side of a mirror or other reflective element. A blended reality view can be used to provide a visual representation of the user in different settings other than the one the user is actually in. Similarly, the blended reality view can be used to provide a visual representation of items, such as clothes, on the user without the user actually wearing the physical item.

Display systems can be used to provide a view of objects that are not actually in a scene but that are perceived to be there by a user. This can be accomplished using angled glass and lighting techniques. Teleprompters, amusement park rides, heads up displays, visual illusions, and the like employ similar methods for providing a user a view of a portion of reality (e.g., light transmitted from a scene through the angled glass) along with a portion of projected objects (e.g., light reflected from an object or display by the angled glass).

However, challenges arise when it is desirable to combine a reflection of a user with projected images of virtual objects. Using angled glass with special lighting techniques does not provide such a view because the angled glass does not reflect an image of the user back to the user. In addition, attempting to combine a reflected view of the user with a view of projected images can result in undesirable superposition of reflections with projected images, sometimes called "ghosting." Without controlling which objects are seen as reflections by a user, this undesirable combination of reflected images with transmitted or projected images can result in an unclear image being perceived by the user.

In addition, visual displays that employ angled glass to project images to a user can use additional space for a display placed out of the direct line of site of the user. This can increase the size of a visual display making it difficult or cumbersome to install and/or use.

Accordingly, the present disclosure provides systems and methods that generate a blended reality view by controlling the amount of light transmitted through a mirror and the amount of light reflected from the mirror. Blended reality apparatuses and methods described herein reduce or eliminate undesirable superposition of reflected and projected images by controlling the amount of light transmitted through a mirror and an amount of light reflected by the mirror. Using a blended reality apparatus as disclosed herein, a viewer can see reflected light in a first region of a mirror, transmitted light in a second region of the mirror, and a controlled superposition of reflected and transmitted light in a third region of the mirror. Blended reality apparatuses disclosed herein can be configured to control which portions of a mirror provide reflected light to a user, which portions of the mirror provide transmitted light to the user, and which portions of the mirror provide a controlled superposition of reflected and transmitted light to the user. This may be desirable in a situation where a user wants to see how a new outfit would look in a particular setting. To generate a blended reality view, a blended reality apparatus can i) selectively illuminate the user, ii) leave the rest of the room dark, and/or iii) project an image of the particular setting (e.g., a restaurant), the projected image being shown on the display at a location where the user would have seen a reflection of objects or surfaces in the room. Because the user is illuminated, the user can see their reflection. Because the rest of the room is dark but the apparatus is projecting an image of the particular setting, the user can see the setting

instead of a reflection of the room. Furthermore, the apparatus can also project an image of the new outfit so that the user sees a superposition of their reflection with the projected new outfit so that it appears as though the user is wearing the outfit.

The blended reality systems and methods disclosed herein can provide a blended reality view using a mirror that is transmissive and reflective, a plurality of projectors to selectively illuminate objects in a room in front of the mirror, and a display to selectively transmit images through the mirror. To provide the blended reality view, projectors can selectively illuminate objects in a room and the display can be used to project images through the mirror. Depending on the area of the mirror the user looks at, the light reaching the user's eye can be dominated by light reflected by the mirror, dominated by light transmitted through the mirror, or a combination of reflected and transmitted light. Thus, the blended reality view can be a combination of reflected images and transmitted images where the images are perceived by the user as a single scene. Furthermore, the blended reality systems and methods disclosed herein can provide the blended reality view using an apparatus that is compact relative to designs employing angled glass because the display and mirror can be attached or otherwise combined with one another so that a surface of the mirror is adjacent to and parallel to a surface of the display.

Although the examples and implementations described herein focus, for the purpose of illustration, on displays, projectors, cameras, and mirrors for generating blended reality views, one skilled in the art will appreciate that the techniques described herein may be applied to other processes, methods, or systems. For example, the techniques may be used with other types of visual displays that collect and process image data for purposes other than providing a blended reality view to a user, but instead generate visual impressions for a user or a group of users by combining transmitted images with reflections. Various aspects of the disclosure will now be described with regard to certain examples and embodiments, which are intended to illustrate but not limit the disclosure.

In one aspect, an apparatus can be configured to provide a user a simultaneous view of reflected and transmitted light to create a visual effect for the user that blends reflections with displayed images. The apparatus can include a mirror that is partially-reflective and partially-transmissive and a display device positioned on a first side of the mirror, the display device having a screen configured to generate light transmitted through the mirror. The apparatus can include a plurality of projectors positioned on a periphery of the mirror and oriented to project light onto a user when the user is positioned on a second side of the mirror, opposite the first side. The apparatus can include a camera configured to acquire image data of the user and the environment or scene on the second side the mirror. The apparatus can include an image blending system communicably coupled to the camera, the display device, and the plurality of projectors. The image blending system can be configured to determine a location of a user's eyes based on the image data acquired with the camera, display images with the display device so that portions of the screen are illuminated and portions of the screen are not illuminated, and control the projectors to illuminate portions of the user and/or objects in the scene. When the user views the mirror, the user sees a reflection from the mirror of illuminated objects in the scene and the transmitted images from the display device through the mirror, the transmitted images being perceived as part of the reflected scene.

Overview of an Example Blended Reality Apparatus

Turning now to FIG. **1**A, an example blended reality apparatus **100** is illustrated that is configured to generate a blended reality view **116** for a user **105** by combining light reflected by a mirror **120** with light from a display device **110** transmitted through the mirror **120**. The blended reality apparatus **100** includes a plurality of projectors **130** around or near a frame **125** of the mirror. The plurality of projectors **130** is configured to selectively illuminate objects in front of the mirror **120**. The blended reality apparatus **100** includes one or more cameras **140** on or near the frame **125** of the mirror. The one or more cameras **140** are configured to acquire image data of the user **105** and objects in front of the mirror **120**.

The blended reality apparatus **100** can generate the blended reality view **116** by controlling the illumination of objects in front of the mirror **120** using the projectors **130** and by generating images with the display device **110** behind the mirror **120**. The blended reality view **116** includes a combination of reflected light (e.g., a reflection **122** of the user) and transmitted light (e.g., a beach scene **112** or a shirt **117** projected by the display device **110**, as described herein with reference to FIGS. **1**B and **1**C, respectively). To generate the blended reality view **116**, the blended reality apparatus **100** can use the one or more cameras **140**. In a scanning phase, the one or more cameras **140** can be used to acquire image data of the environment in front of the mirror **120**, where the environment in front of the mirror **120** includes objects, surfaces, and/or light sources that can be seen reflected in the mirror **120**. In some embodiments, this first phase, or scanning phase, occurs during an initial setup of the blended reality apparatus **100**. From this image data, a three dimensional virtual model of the environment can be generated. For example, simultaneous localization and mapping ("SLAM") techniques can be used to generate the virtual model. SLAM techniques can include acquiring image information of an environment to update an estimate of a position or positions of an object's location in the environment using Kalman filters, particle filters, and Monte Carlo methods. Other methods include combining information from optical cameras, infrared cameras, and/or range finders to determine and track locations of objects. Examples of such techniques can be found, for example, in U.S. Pat. No. 8,744,121 entitled "Device for Identifying and Tracking Multiple Humans Over Time," U.S. Pat. No. 8,717,417 entitled "Three-Dimensional Mapping and Imaging," and U.S. Pat. Pub. No. 2010/0302138 entitled "Methods and Systems for Defining and Modifying a Visual Representation," each of which is incorporated herein by reference in its entirety. In some embodiments, the one or more cameras **140** can be used to update the three dimensional virtual model from time to time, such as when requested by a user, at regular intervals, and/or when changes to the environment are detected.

In addition, during a tracking phase, the one or more cameras **140** can be used to acquire image data of the user **105** when the user is using the blended reality apparatus **100**. The image data of the user **105** can be used to track the user's face and/or to determine the location of the user's eyes in relation to the mirror **120**. The one or more cameras **140** can each have a field of view. The one or more cameras **140** can be configured to image a user positioned within the field of view of at least one of the one or more cameras **140**. The field of views of one or more cameras **140** can overlap to provide regions where image information of the user is acquired from a plurality of angles. Accordingly, the blended reality apparatus **100** can perform the tracking phase when

the user **105** is positioned within the field of view of at least one camera. In some embodiments, tracking of the user's face and/or the user's eyes may improve when the blended reality apparatus **100** includes a plurality of cameras and the user is positioned within the field of view of at least two cameras. In some embodiments, the blended reality apparatus **100** is configured to track the user's face and/or to determine the location of the user's eyes when the user is positioned in front of the mirror **120** such that the user **105** can see the user's own reflection (e.g., the user **105** is not positioned outside the frame **125** of the mirror **120**). Example systems and methods configured to track a human head, face, and/or form in real time are described, for example, in U.S. Pat. No. 8,594,425 entitled "Analysis of three-dimensional scenes," and U.S. Pat. Pub. No. 2013/0202161 entitled "Enhanced Face Detection Using Depth Information," each of which is incorporated herein by reference in its entirety. In some embodiments, facial tracking is accomplished through the use of the Kanade-Lucas-Tomasi ("KLT") algorithm.

In some embodiments, the user's face can be tracked in real time or near real time with the one or more cameras **140**. With the user's eyes located, reverse ray tracing (e.g., tracing rays of light from the user's eye to the mirror and to the environment) or other techniques can be performed to determine and associate the different parts of the environment the user can see. This information can then be used to control the projectors **130** to selectively illuminate objects and/or surfaces in the environment. This information can also be used to control the display device **110** to selectively illuminate portions of the mirror **120** from behind the mirror **120**.

By way of analogy, in one embodiment, the mirror **120** can be thought of as a single pixel-based screen showing two images to be blended. The first image is the reflection of the user **122** and/or objects in the environment. Objects in the environment can include furniture, clothes, books, toys, devices, and the like. Objects in the environment can also include walls, floors, ceilings, or other structures. Objects in the environment can also include any surface, texture, or other feature visible as a reflection in the mirror **120**. The first image can be calculated based on the user's eye position from the image data acquired with the one or more cameras **140**. For example, reverse ray tracing can be done to determine the objects visible in the mirror using information about the user's eye position and the locations of objects in the environment. The second image is the virtual image **112** generated by the display device **110** where the virtual image **112** is transmitted through the mirror **120**. The blending of the two images can be accomplished by controlling the relative intensities of the light in both images. For example, light intensity and/or color at each pixel in the display and/or light intensity and/or color projected by the projectors on different objects can be varied to achieve a desired mixing of light at the user's eye. At each "pixel" or location on the mirror **120**, the image seen by the user corresponds to the image providing the most light at that pixel. For example, if the first image, or reflection, is to be seen at a particular location on the mirror **120** then the projectors **130** can be configured to illuminate whatever object the user will see when looking at the mirror **120** at that particular location on the mirror **120**. This determination is based on the location of the user's eyes and the three dimensional virtual model of the environment. The display device **110** can be dark, blank, display a solid color (e.g., black, white, blue, or other color), or display a selected pattern at the corresponding location. If on the other hand the second image, or virtual image, is to be seen at a particular location on the mirror **120** then the display device **110** can be configured to transmit light from behind the mirror **120** using a pixel or collection of pixels that corresponds to that particular location on the mirror **120**. The projectors **130** can be configured to not illuminate whatever object the user sees when looking at the mirror **120** at that particular location on the mirror **120**. As a result, the user **105** sees at each "pixel" or location on the mirror **120** reflected light or transmitted light. The user then perceives a blending of the two images resulting in a single blended reality scene.

FIG. **2** illustrates a diagram of a user **105** simultaneously perceiving reflected light and transmitted light, wherein the respective intensities of the reflected and transmitted light are controlled by the projectors **130**, the display device **110**, and/or ambient light sources **135***a*, **135***b*. The blended reality apparatus **100** can be configured to control the light in the environment using the projectors **130**. The light from the projectors **130** can be controlled to control reflected light intensity at the mirror **120** on a "per pixel" basis meaning that the image or light pattern projected by each projector **130** can be configured to result in desired reflected light intensity at particular locations on the mirror **120**. In some embodiments, the blended reality apparatus **100** can also control ambient lighting in the environment using lights **135***a*, **135***b* in the environment or lights outside of the environment. The lights **135***a*, **135***b* are generally not controllable on a "per pixel" basis because they are generally diffuse sources of light. However, the intensity and/or color of light from the lights **135***a*, **135***b* can be controlled. Furthermore, the blended reality apparatus **100** can be configured to control transmitted light using the display device **110**. The display device **110** can also be controlled on a "per pixel" basis.

As shown in FIG. **2**, the user **105** will perceive an image based on the light arriving at the user's eye. In the figure, solid lines **113**, **114** represent transmitted light from the display device **110** and dashed lines **123**, **124** represent light reflected from surfaces in the environment. The thickness of the lines corresponds to the relative intensity of the light. When looking at a particular region of the mirror **120**, the user will perceive a transmitted or virtual image if light from the display device **110** transmitted through the mirror **120** in that region dominates the light from a surface **150***a* reflected from that region of the mirror **120** (e.g., transmitted light **113** dominates reflected light **123**). To increase the contrast between transmitted light and reflected light, the surface **150***a* can be left unilluminated by the projectors **130**. The contrast between transmitted light and reflected light can be the difference in light intensity of the two sources. For example, the contrast between transmitted light and reflected light can be expressed as (IT−IR)/(IT+IR), where IT is the intensity of transmitted light and IR is the intensity of reflected light. When looking at a particular region of the mirror **120**, the user will perceive a reflected image where light from a surface **150***b* reflected at the particular location on the mirror **120** dominates light transmitted by the display device **110** through the mirror at the particular location (e.g., the reflected light **124** dominates transmitted light **114**). To increase the contrast between reflected and transmitted light, the surface **150***b* can be illuminated by the projectors **130**. In some situations, it may be undesirable for a user to see a combination of reflected light and transmitted light at a single "pixel" or location on the mirror **120**. This undesirable combination can be reduced or eliminated by increasing the contrast between the reflected and transmitted light. To reduce or eliminate undesirable superposition of reflected

and transmitted images, the intensity of the light that is not to be perceived can be reduced or eliminated. In the case of the display device **110**, this can mean not illuminating that portion of the display device **110** or using an active element to block that portion of the display device **110**. Examples of such active elements are described in greater herein with reference to FIGS. **3**B and **6**B. In the case of reflections from objects in front of the mirror, this can mean not illuminating the surface with the projectors **130** and/or reducing or eliminating ambient lighting. In some situations, it may be desirable for a user to see a combination of reflected light and transmitted light at a location on the mirror **120**. The desirable combination can be controlled by controlling the respective intensities of reflected and transmitted light. As used herein, intensity of light can be used to mean the number of photons per unit area per solid angle (e.g., radiant intensity), or power emitted by a light source weighted according to the sensitivity of the human eye (e.g., luminous intensity), brightness of a light source, or other such measurement used to quantify the power emitted by a light source or perceived by a viewer. In some embodiments, the ratio of intensities of light can be configured to achieve a desired effect. For example, where the user sees reflected light, the ratio of intensities of reflected light to transmitted light can be about 2:1, about 3:1, about 4:1, about 5:1, or greater than about 5:1. Similarly, where the user sees transmitted light, the ratio of intensities of transmitted light to reflected light can be about 2:1, about 3:1, about 4:1, about 5:1, or greater than about 5:1.

In some embodiments, it may be desirable to blend transmitted light with reflected light. This can be accomplished by varying the intensity of illumination provided by the projectors **130** on a surface and the intensity of the light provided by the display device **110**. The relative intensities of reflected and transmitted light can be varied to produce desired effects, such as overlaying a virtual image on a reflected image. For example, this can be used to show the user **105** how an article of clothing or make up would look on the user **105**.

In some embodiments, the blended reality apparatus **100** is configured to illuminate the user **105** and objects in the environment so that the user sees the user's own reflection while reflections of objects in the environment are reduced or eliminated. This can be used to substantially isolate the user's reflection. This can reduce computational costs due at least in part to the blended reality apparatus **100** not determining what to display in each pixel or location of the mirror **120**. Rather, the blended reality apparatus **100** determines the portions of the user to illuminate with the projectors **130** while leaving the rest of the environment without illumination from the projectors **130**. In some implementations, the display device **110** displays a substantially uniform color or pattern to help in isolating the reflection of the user **105**.

To generate a blended reality view where the user sees the user's own reflection along with an artificial scene, the display device **110** of the blended reality apparatus **100** can be configured to project an image or light from targeted pixels and project no relatively little light at other targeted pixels. An example of this is illustrated in FIG. **1**B. FIG. **1**B illustrates the display device **110** of the blended reality apparatus **100** illustrated in FIG. **1**A, with the mirror **120** and other components removed. The display device **110** includes a screen **111** that displays an image **112** (e.g., the beach scene **112**) but with a portion of the screen **111** shown in black. This black portion **118** corresponds to the portion of the mirror **120** where a reflection of the user **105** is to be perceived by the user **105** rather than an image transmitted by the display device **110**. The black portion **118** can be configured to transmit little or no light so that the light reflected from the mirror **120** at that location on the mirror **120** dominates the light transmitted through the mirror **120** at that location on the mirror **120**. The size, shape, color, and other properties of the black portion **118** can change depending on the targeted or desired blended reality view **116** provided to the user. For example, in some cases the black portion **118** can include projected images, colors, textures, patterns, or the like that are intended to be mixed with reflected images so that the user perceives a combination of transmitted and reflected light. The shape of the black portion **118** can be determined based on the location of the user's eyes as well as the desired or targeted blended reality view **116**. For example, as described herein, the blended reality apparatus **100** can utilize reverse ray tracing or other techniques to determine which portions of the display device **110** to illuminate and how to illuminate those portions. The blended reality apparatus **100** can use images of the user **105** acquired with the one or more cameras **130** to update the shape of the user's body to change the shape of the black portion **118** as the user **105** moves. The blended reality apparatus **100** can be configured to update the shape of the black portion **118** in real time.

To generate a blended reality view where the user sees an article of clothing or other object superimposed on the user's body, the display device **110** of the blended reality apparatus **100** can again be configured to project an image or light from targeted pixels and project no relatively little light at other targeted pixels. An example of this is illustrated in FIG. **1**C. The display device **110** in this scenario displays an image of a shirt **117** such that the user **105** views the image of the shirt superimposed on the user's body. The image of the shirt **117** can be adjusted to fit the body of the user by adjusting the size of the shirt based on an analysis of images of the body of the user acquired with the one or more cameras **140**. In some embodiments, a visual approximation can be made to adjust the properties of the shirt **117** as displayed by the display device **110**. The visual approximation can be based on images of the shirt acquired when the shirt was worn by another person, wherein the images of the shirt are adjusted based on the body of the user **105**. The concepts described with reference to FIGS. **1**B and **1**C can be combined. For example, the blended reality apparatus **100** can be configured to provide a blended reality view that includes a projected scene to change an environment around the user **105** (e.g., the beach scene **112** illustrated in FIG. **1**B) and an object to be perceived as being worn by the user **105** (e.g., the shirt **117** illustrated in FIG. **1**C).

Additionally, the blended reality apparatus **100** can be configured to substantially isolate a reflection of the user **105** such that a reflection of environment around the user is suppressed. For example, this may be accomplished by using the display device **110** to project a tailored scene **112** around the user **105** (e.g., a substantially uniformly lit scene, a scene that is substantially white, a scene that is substantially black, a scene lacking sharp details, a scene lacking discernible objects, or the like) and/or by not illuminating objects in the environment with the projectors **130**. By isolating the user's reflection, the user **105** may be able to focus more on the user's own reflection due at least in part to a reduction of potentially distracting objects being viewed by the user **105** in the mirror **120**. This can also reduce the computational costs associated with generating a blended reality view that includes objects or scenes to be viewed along with the reflection of the user **105**.

Returning to FIG. **1**A, the display device **110** of the blended reality apparatus **100** is positioned on a first side of the mirror **120**. In use, the user **105** can be positioned on a second side of the mirror **120**, opposite the first side, so that the user **105** can see the user's own reflection in the mirror **120**. The display device **110** can be a device having a screen, such as an LCD or plasma television, or the display device **110** can be a projector. In some embodiments, the display device **110** is configured to be parallel to the mirror **120**. In some embodiments, a screen of the display device **110** is configured to have a width that is substantially the same width as the mirror **120** and a height that is substantially the same height as the mirror **120**. In some embodiments, the display device **110** can be configured to project images that can substantially cover the surface area of the mirror **120**. For example and without limitation, the width of the screen or the width of the projected image can be at least 80% and/or less than or equal to about 120% the width of the mirror **120**, at least 90% and/or less than or equal to about 110% the width of the mirror **120**, at least 95% and/or less than or equal to about 105% the width of the mirror **120**, or at least 97% and/or less than or equal to about 103% the width of the mirror **120**. Similarly, the height of the screen or the height of the projected image can be at least 80% and/or less than or equal to about 120% the height of the mirror **120**, at least 90% and/or less than or equal to about 110% the height of the mirror **120**, at least 95% and/or less than or equal to about 105% the height of the mirror **120**, or at least 97% and/or less than or equal to about 103% the height of the mirror **120**. In some embodiments, the display device **110** can be made up of multiple displays and/or screens.

The display device **110** can be attached to the mirror **120** to form a unitary structure. In some embodiments, the display device **110** can be attached to the mirror **120** so that the display device **110** can be removed or replaced without damaging the mirror **120**. The display device **110** can have a surface that is adjacent to and parallel to a surface of the mirror **120**. In this configuration, the blended reality apparatus **100** can have a depth that is a combination of the thickness of the mirror **120** and the thickness of the display device **110**. This can result in a relatively compact apparatus suitable for installation in many environments, such as in a fitting room, in a closet, and/or hung on a wall.

The mirror **120** can be a sheet of material that is reflective and transmissive, such as glass or acrylic. The mirror **120** can be treated to balance transmittance, reflectance, and absorptance properties to achieve targeted or desired results. The mirror **120** can be a half-silvered mirror, similar to a beam splitter, that has balanced reflectance and transmittance properties in the visible spectrum (e.g., the mirror's reflectance and transmittance are about equal in the wavelength range between 350 nm and 700 nm). The mirror **120** can be planar or it can have a curved surface. The front side of the mirror **120** can be designated as the side of the mirror **120** facing the user **105** when the user **105** is viewing their reflection. With this convention, the display device **110** is positioned facing the back side of the mirror **120** so that light emitted from the display device **110** passes through the mirror **120** from the back side to the front side to eventually reach the user **105**. The mirror **120** can include the frame **125** to provide support for the mirror **120** as well as providing a place to attach the one or more cameras **140** and/or the projectors **130**.

The projectors **130** of the blended reality apparatus **100** can be positioned around the mirror **120**, such as integrated into the frame **125** of the mirror **120**. The projectors **130** can be configured to project light into the environment in front of the mirror (e.g., where the user **105** stands when perceiving the blended reality view **116**). As described in greater detail herein, the projectors **130** can be positioned at other locations. The blended reality apparatus **100** can include at least 2 projectors, at least 3 projectors, at least 4 projectors, at least 5 projectors, at least 6 projectors, at least 7 projectors, at least 8 projectors, more than 8 projectors, or less than 10 projectors. In some embodiments, the projectors **130** can be positioned along at least two orthogonal axes. For example, projectors can be positioned at the midpoints of the frame **125** or at the corners of the frame **125**. The projectors **130** can be configured to generate a combined light output as if positioned at the user's eyes to achieve targeted or desired lighting effects. The combined light output from the projectors **130** can be configured to illuminate desired or targeted surfaces in the environment (including the user) and to leave other surfaces without illumination from the projectors. In some embodiments, the projectors **130** can be coupled to motors or other actuators to change an orientation of the projectors **130**. This can be done to change the pointing direction of the projectors **130** to enable illumination of different objects.

The one or more cameras **140** of the blended reality apparatus **100** can be attached to the mirror **120** or positioned elsewhere. The one or more cameras **140** can be configured to acquire image data of the environment in front of the mirror **120**. The one or more cameras **140** can be configured to acquire image data of the user **105** when positioned in the environment in front of the mirror **120**. The one or more cameras **140** can include image acquisition devices sensitive to different portions of the electromagnetic spectrum. For example, at least one camera can be sensitive to light in the visible portion of the spectrum and at least one camera can be sensitive to light in the infrared portion of the spectrum. The one or more cameras **140** can also include time of flight cameras or other similar sensors configured to determine distances to objects or surfaces in the environment. The one or more cameras **140** can include depth finding or range finding devices configured to determine a distance to one or more objects within a field of view of the respective device. In some embodiments, the one or more cameras **140** can be coupled to motors or other actuators to change an orientation one or more of the cameras **140**. This can be done to change the pointing direction of one or more of the cameras **140** to acquire images of different objects and/or to track movements of the user or objects.

The information acquired with the one or more cameras **140**, such as image and/or depth information, can be used to construct a virtual model of the environment for the blended reality apparatus **100**. The virtual model can include a digital representation of objects and surfaces in the environment and their relative positions, orientations, colors, reflectivities, and the like. The virtual model can be used to determine the patterns of light or images to be generated by the one or more projectors **130** to achieve a targeted or desired reflected image for the user **105**. Example systems and methods for constructing three dimensional virtual models of an environment using image data are described in U.S. Pat. No. 8,594,425 entitled "Analysis of three-dimensional scenes," U.S. Pat. No. 8,717,417 entitled "Three-Dimensional Mapping and Imaging," U.S. Pat. No. 8,326,025 entitled "Method for Determining a Depth Map from Images, Device for Determining a Depth Map," and U.S. Pat. No. 8,649,025 entitled "Methods and Apparatus for Real-Time Digitization of Three-Dimensional Scenes," each of which is incorporated herein by reference in its entirety.

In some embodiments, the blended reality apparatus **100** can be configured to perform a light-based scan of the environment to determine properties of the environment. This information can be used to determine the light to be projected by the projectors **130** and/or ambient lights. In certain implementations, the blended reality apparatus **100** performs this scan instead of constructing a virtual model of the environment. This can reduce the computational costs of generating a blended reality view. As an example, the blended reality apparatus **100** can be configured to incrementally increase or decrease the intensity of ambient lights or projectors **130** to illuminate the environment. The one or more cameras **140** can acquire images of the environment at the different levels of illumination. Based at least in part on the acquired images, the blended reality apparatus **100** can be configured to determine properties of the environment (e.g., color, reflectivity, etc.). Using these properties, the blended reality apparatus **100** can determine the targeted illumination to be provided by the projectors **130** to generate a targeted blended reality view. In certain implementations, the blended reality apparatus **100** controls the projectors **130** and/or ambient lights to illuminate targeted portions of the environment to characterize the optical properties of those targeted portions. Again, using the characterized optical properties of the environment (e.g., color, reflectivity, etc.), the blended reality apparatus **100** can determine the targeted illumination to be provided by the projectors **130** to generate a targeted blended reality view. In some implementations, the blended reality apparatus **100** can be configured to use depth information acquired with the one or more cameras **140** to determine the illumination pattern provided by the projectors **130**. For example, the depth information can be used to determine which objects are background objects and which objects are foreground objects (e.g., such as the user **105**). The blended reality apparatus **100** can then illuminate the foreground objects with the projectors **130** while leaving the background objects unilluminated. In some implementations, the blended reality apparatus **100** can be configured to project patterns of light onto surfaces in the environment to generate depth maps of the environment. Examples of systems and methods for generating depth maps using projected light and/or acquired images of an environment are described in U.S. Pat. No. 8,493,496 entitled "Depth Mapping Using Projected Patterns," U.S. Pat. No. 8,326,025 entitled "Method for Determining a Depth Map from Images, Device for Determining a Depth Map," and U.S. Pat. No. 8,649,025 entitled "Methods and Apparatus for Real-Time Digitization of Three-Dimensional Scenes," each of which is incorporated by reference herein in its entirety.

The one or more cameras **140** can also be used to identify and track a face of the user **105** to determine the location of the user's eyes. Any suitable method or algorithm can be used to accomplish this. For example, an infrared beam and an infrared camera can be used to determine the location of the users' eyes based on reflected infrared light from the retinas. Other facial and/or eye tracking systems and methods are described in U.S. Pat. No. 8,408,706 entitled "3D Gaze Tracker," U.S. Pat. No. 6,578,962 entitled "Calibration-Free Eye Gaze Tracking," and U.S. Pat. No. 7,197,165 entitled "Eye Tracking Using Image Data," each of which is incorporated herein by reference in its entirety.

The blended reality apparatus **100** can be used in a number of ways. A first example involves reflecting the head and shirt of a user and transmitting an image of clothing on the rest of the user, thereby providing a blended reality view that shows the user what the user was wearing the last time the user wore that shirt. To accomplish this, the blended reality apparatus **100** can control the projectors **130** to illuminate the head and shirt of the user so that they are reflected to the user and control the display device **110** to transmit an image or images of the other articles of clothing the user was wearing. A second example involves providing a reflection of the user along with transmitted scenes of different environments. This may be desirable when the user is trying on clothing to provide the user a view of how the outfit would look in different settings. The blended reality apparatus **100** can control the projectors **130** to illuminate the user so that the user sees their own reflection and control the display device **100** to transmit images of different settings. The result can be that the actual surroundings of the user (e.g., the user's closet or a dressing room) are replaced with images of the beach, a restaurant, an office, or the like. The ambient lights can also be adjusted to accomplish a targeted or desired effect.

FIG. **3**A illustrates a top view of the example apparatus **100** of FIG. **1**A, wherein the apparatus **100** includes a plurality of projectors **130** configured to selectively illuminate surfaces **150***a-d* within an environment in front of the mirror **120**. The projectors **130** can be high-contrast projectors configured to project a range of visible wavelengths with high dynamic range. The projectors include modulating panels (e.g., liquid crystal on silicon panels, liquid crystal device panels, digital micromirror device panel, etc.) configured to generate patterns of light for projection. The projectors **130** can be configured to project light at targeted areas. As an example, to illuminate object **150***c* so that its reflection is seen in the mirror **120** by the user **105**, each projector **130** can determine (e.g., through an analysis of the virtual model of the environment created by the blended reality apparatus) the pattern of light necessary to illuminate object **150***c* but to not illuminate, for example, object **150***d*. The combined light output from the projectors **130** can thus illuminate targeted objects or surfaces in the environment while leaving others dark.

FIG. **3**B illustrates a top view of the example apparatus **100**, the apparatus **100** including an active transmission matrix **115** between the display **110** and the mirror **120**. The active transmission matrix **115** comprises an active electronic element that can change the optical properties of individual pixels in the matrix. For example, the active transmission matrix **115** can be a liquid crystal matrix configured to control individual pixels, changing selected pixels from opaque to transparent (e.g., a pixel will block or transmit light) to further regulate the light transmitted from the display device **110** through the mirror **120**. This can improve control over reflected and transmitted light perceived by the user. The active transmission matrix **115** can also be a material that can selectively change individual pixels from opaque to reflective or from transmissive to reflective. In some embodiments, the active transmission matrix **115** can be integrated with the mirror **120** or integrated with the display device **110**. In some embodiments, the active transmission matrix **115** is the mirror **120** such that the mirror **120** can change the reflectance of individual pixels on a face of the mirror **120**. For example, the active transmission matrix **115** can include a liquid crystal switchable mirror comprising a solid state thin film device that can be configured to switch between reflective, partially reflective, and transparent states. Examples of such apparatuses are disclosed in U.S. Pat. No. 6,999,649 entitled "Optical Switches Made by Nematic Liquid Crystal Switchable Mirrors, and Apparatus of Manufacture," which is incorporated herein by reference in its entirety. This implementation advantageously provides greater control over

reflected and transmitted images seen by the user. The active transmission matrix **115** and the projectors **130** can thus combine to enhance the blended reality image by providing greater control over the transmission and reflection of light at the mirror **120**.

FIG. **4** illustrates an example apparatus **400** configured to generate a blended reality view, the apparatus **400** configured to control lighting within an environment to enhance the blended reality view. The blended reality apparatus **400** includes hue lights **133** around a periphery of the mirror. The hue lights **133** can be controlled to change the color and/or intensity of light within a room and/or on a wall behind the blended reality apparatus **400** to enhance the generated blended reality view. The hue lights **133** can be any suitable light or combination of lights providing a single color or a range of colors in the visible spectrum. For example, the color and/or intensity of the hue lights **133** can be configure to change based on the blended reality view perceived by the user at the mirror **120**. If the blended reality view includes the user on a boat in the ocean, the hue lights **133** can be configured to shine blue shimmering light on the walls, floor, and/or ceiling or other objects to enhance the blended reality experience. The hue lights **133** can include strands of LED lights around a frame of the blended reality apparatus **100** that change depending on what is transmitted and/or reflected by the apparatus **100**.

The blended reality apparatus **400** can also be configured to control lighting fixtures **135**. The lighting fixtures can be sources of diffuse light or directed light positioned throughout the environment in which the blended reality apparatus **400** will be used. The lighting fixtures **135** can provide isotropic, diffuse, anisotropic, and/or directional light (e.g., spotlights). However, the lighting fixtures **135** and the hue lights **133** differ from the projectors **130** in that the projectors **130** can modulate the light they produce to provide a targeted or desired light output (e.g., by modulating pixels to project a pattern of light that can change over time) whereas the lighting fixtures **135** and/or hue lights **133** can be controlled to change a direction, brightness and/or color of the light, but not to generate a targeted pattern of light output.

FIG. **5**A illustrates a top view of an example blended reality apparatus **500** for generating a blended reality view, the blended reality apparatus **500** including projectors **130** and cameras **140** positioned around and within an environment in front of a mirror **120**. The projectors and cameras **140** positioned in such a manner can improve the generated blended reality view. For example, cameras **140** positioned around the environment can be used to improve the scan of the environment and the resulting virtual model. An improved virtual model can be used to improve control of the projectors **130** to more exactly illuminate desired surfaces. Similarly, projectors **130** positioned around the environment can be used to improve the targeted illumination of surfaces by providing additional angles and optical pathways to surfaces that may otherwise be occluded. The cameras **140** and projectors **130** can be positioned at various heights with various pointing angles. For example, cameras **140** and/or projectors **130** can be positioned on ceilings, walls, objects, floors, and/or other surfaces. This can advantageously increase the ability to selectively illuminate objects **150***a-d* and/or not illuminate these objects.

In some embodiments, the additional cameras **140** and projectors **130** can be used to provide additional views of the user in addition to and/or instead of reflected views of the user. For example, cameras **140** positioned behind the user can provide a rear view of the user so that the user can see how clothes appear from that angle.

FIG. **5**B illustrates a top view of a blended reality system **550** comprising a plurality of apparatuses **500***a-d*, each blended reality apparatus **500***a-d* configured to generate a blended reality view for a user **105**. Each blended reality apparatus **500***a-d* can include a display device **110**, a mirror **120**, projectors **130**, and one or more cameras **140**. Each blended reality apparatus **500***a-d* can operate independently to generate blended reality views for the user. In some embodiments, the blended reality apparatuses **500***a-d* are communicably coupled so that each apparatus **500***a-d* can receive, for example, image data from the cameras **140** of the other apparatuses and/or control the projectors **130** of the other apparatuses. For an individual blended reality apparatus, this can provide the advantages described with respect to the blended reality apparatus **500** described herein with reference to FIG. **5**A. As an example use, the blended reality system **550** can be used in retail outlets in dressing rooms or other areas where users try on clothes prior to purchasing them. The blended reality system **550** can be used to provide a plurality of simultaneous blended reality views for the user, generating an immersive blended reality environment.

FIG. **6**A illustrates a functional block diagram of an example blended reality apparatus **600***a* comprising an image blending system **660**. The blended reality apparatus **600***a* is configured to acquire image data with the camera(s) **140**, process that image data with the image blending system **660**, and to control the light output of the projectors **140** and/or other lighting (e.g., lighting fixtures or hue lights) to control which objects in an environment are reflected to a user for viewing. In addition, the image blending system **660** controls the display device **110** to generate images at a screen **111** for transmission through the mirror to the user. The combination of the reflected light and the transmitted light forming a blended reality view based on the image information provided by the camera(s) **140**. The image information provided by the camera(s) **140** to the image blending system **660** can include scans of the environment in front of the mirror **120**, images of the user, and/or depth information for objects and/or surfaces in the environment. In some embodiments, the camera(s) **140** can detect motion of the user or other objects in the environment to allow the image blending system **660** to actively compensate for such movement in real time.

FIG. **6**B illustrates a functional block diagram of an example blended reality apparatus **600***b* comprising the image blending system **660** with an additional active transmission matrix **115** relative to the blended reality apparatus **600***a* described with reference to FIG. **6**A. The active transmission matrix **115** can further be controlled by the image blending system **660** to provide greater control over the transmission of light from the screen **111** of the display device **110** and/or to provide greater control over the reflective properties of the mirror **120**.

FIG. **7** illustrates a functional block diagram of an example imaging blending system **660**. The image blending system **660** can receive input from the camera(s) **140** as well as user input **695**. The user input **695** can be received via voice commands, motion-based commands, touch interface controls, wireless signals, or the like. The image blending system **660** can include a controller **665** and data storage **670** configured to respectively execute and to store computer executable instructions for performing the functions described herein. The components and modules of the image blending system **660** communicate with one another via communication bus **692** that can include wired communi-

cation, wireless communication, or a combination of wired and wireless communication. In some embodiments, the components and modules of the image blending system **660** form a single computational system comprising computational hardware. In some embodiments, components of the image blending system **660** can be distributed among other components of a blended reality apparatus. For example, eye tracking functionality can be implemented by an eye tracking module **675** that can be include in one or more cameras **140**.

The image blending system **660** includes an eye tracking module **675** configured to analyze image data acquired by the cameras **140** and to determine an eye location of a user. The eye tracking module **675** can use any suitable method for determining eye position such as using an IR beam and IR camera to identify retinal reflections. Other example methods and systems are described in U.S. Pat. No. 8,408,706 entitled "3D Gaze Tracker," U.S. Pat. No. 6,578,962 entitled "Calibration-Free Eye Gaze Tracking," and U.S. Pat. No. 7,197,165 entitled "Eye Tracking Using Image Data," each of which is incorporated herein by reference in its entirety. In some embodiments, the eye tracking module **675** is configured to track eye movements of the user in real time or in near real time. For example, the eye tracking module **675** can be configured to track eye movement of the user with sufficient speed to allow a blended reality apparatus to modify the transmitted and/or reflected light at the mirror so that the user does not notice any lag between the user's movement and updates to the blended reality view provided.

The image blending system **660** includes an environment scan module **680** configured to analyze image data acquired with the cameras **140** of the environment around a blended reality apparatus. The environment scan module **680** can receive image data from the cameras of one or more views of the environment where the blended reality apparatus is used to determine positions and orientations of objects and/or surfaces in the environment. The environment scan module **680** can then construct a digital representation of the environment using a three dimensional virtual model. This model can be used to perform reverse ray tracing or other techniques by the image blending system to determine what light to transmit by the display **110** and what patterns to project with the projectors **130**. The environment scan module **680** can be configured to scan the environment upon an initial setup, when commanded by a user, when the image blending system **660** identifies changes to the environment, or at designated times or intervals. The environment scan module **680** can be configured to compare current image data to previously acquired image data to determine if there have been changes to the environment. If changes are detected, the environment scan module **680** can generate a new three dimensional virtual model of the environment. In this way, the virtual model can be updated to provide updated blended reality views when objects or surfaces change in the environment.

The image blending system **660** can include a display module **685** configured to determine the pattern of light to transmit by the display **110** and/or the pattern of pixels to turn off or on by the active transmission matrix. The display module **685** can analyze the virtual model along with the image data from the camera(s) **140** to determine where the user's eyes are and what virtual images are to be provided for the targeted or desired blended reality view. The display module **685** can communicate with the display(s)/active transmission matrix **110** to control transmission of light based on this information.

The display module **685** can be configured to provide different views for a left and a right eye of a user. This can be used to provide stereoscopic views for the user enhancing the sensation of depth in the transmitted images. In some embodiments, the display **110** can include a lenticular lens array and/or use polarized light in conjunction with polarized glasses to provide the stereoscopic experience for the user. In some implementations, the display module **685** can be configured to selectively blur images based on where the user is looking. This can be done to enhance the effect of depth in a transmitted scene. In certain implementations, blurring can be used by the display module **685** to simulate the depth of field of the user's vision to compensate for focal distances to images that the user is not focusing on.

The image blending system **660** can include a lighting module **690** configured to control each projector and/or other lighting element **130** to generate the desired or targeted light patterns. The targeted light patterns can be configured to selectively illuminate the user and/or other objects or surfaces in the environment so that the user sees the reflection of those objects in the mirror. For each projector **130**, the lighting module **690** can determine the targeted light pattern by analyzing the virtual model generated by the environment scan module **680**. For example, knowing the position of a particular projector, the lighting module **690** can be configured to determine a light pattern that shines light on a targeted surface while leaving other surfaces without illumination. The lighting module **690** can determine the light output for each projector **140** as well as the combined light output of a plurality or all the projectors **140** to determine the final lighting effect. The lighting module **690** can thus adjust the light output (e.g., light pattern, light intensity, and/or light color) to selectively illuminate objects so they are viewed as reflections in the mirror by the user.

In some embodiments, the lighting module **690** and the display module **685** can work together to supplement and/or enhance the output of the projectors **130** and the display **110**. For example, where the display module **685** controls the display **110** to transmit images of a beach scene, the lighting module **690** can generate complementary light patterns to improve the visual appearance of the beach scene by projecting the light patterns on a wall or other surface. The result being that the user sees a combined transmitted image and a reflected image of a beach scene, enhancing the immersive and realistic quality of the blended reality view. Similarly, the display module **685** can control the display **110** to transmit images of objects in the room with modifications while the lighting module **690** can control the projectors to selectively illuminate the objects. The result being that the user sees the reflection of the objects combined with transmitted images on those objects, thus enhancing the blended reality view.

FIG. **8** illustrates an example method **800** for generating a blended reality view. The method can be performed by any of the blended reality apparatuses or systems described herein. For ease of description, the method will be described as being performed by a blended reality apparatus, but each step or combination of steps in the method can be performed by a single component or a combination of components in the blended reality apparatus or system.

In block **805**, the blended reality apparatus scans an environment with one or more cameras. The environment can include a room or other location in which the blended reality apparatus is positioned. In some embodiments, the environment includes all objects and/or surfaces in front of the mirror, where the front of the mirror is the part of the mirror viewed by a user to view their reflection. In some

embodiments, the environment includes additional areas that are not in front of the mirror or which are not visible as reflections when positioned in front of the mirror. The scan of the environment can include acquiring image data, depth information, and/or other information about the positions, orientations, and/or optical characteristics of objects and surfaces within the environment.

In block **810**, the blended reality apparatus generates a virtual model of the scanned environment. The virtual model can be a digital representation of the objects and surfaces within the environment, where the positions and orientations of the objects and surfaces are represented. The virtual model can include information about the optical characteristics of those objects and surfaces for purposes of reverse ray tracing when generating a blended reality view. In some implementations, the virtual model includes information about optical characteristics and/or positions of surfaces of the scanned environment, but it is not a digital representation of the objects and surfaces within the environment.

In block **815**, the blended reality apparatus uses image data from one or more cameras to identify a face and/or eyes of a user. The blended reality apparatus can track the user's face and/or eyes in real time to update the blended reality view to compensate for movements of the user.

In block **820**, the blended reality apparatus determines objects or surfaces to be seen as reflections by the user. To generate the blended reality view, the apparatus blends reflections of objects and/or surfaces in the environment, including portions of the user, with transmitted images. In block **825**, the blended reality apparatus generates images to be transmitted by a display through a mirror to the user. In block **830**, the blended reality apparatus projects light onto the user and/or surfaces in the environment so that these things will be viewed as reflections in the mirror. By controlling the amount, quality, and pattern of light projected by each projector, the reflected images can be controlled selectively reflect portions of the user and/or environment. The reflected images and transmitted images can be perceived by the user simultaneously, resulting in a blended reality view. After performing the steps in blocks **825** and **830**, the method returns to block **815** to update the information related to the position of the face and/or eyes of the user. The method can thus track in real time the position of the face and/or eyes of the user to update the blended reality view so that the view changes as the user moves.

Depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the algorithm). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially.

The various illustrative logical blocks, modules, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks and modules described in connection with the embodiments disclosed herein can be implemented or performed by a machine, such as a processor configured with specific instructions, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A processor can be a microprocessor, but in the alternative, the processor can be a controller, microcontroller, or state machine, combinations of the same, or the like. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The elements of a method, process, or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of computer-readable storage medium known in the art. An exemplary storage medium can be coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The processor and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor and the storage medium can reside as discrete components in a user terminal. A software module can comprise computer-executable instructions which cause a hardware processor to execute the computer-executable instructions. The computer-executable instructions can comprise a scripted computer language and/or a compiled computer language. Computer-executable instructions can comprise, for example and without limitation, JAVASCRIPT®, PYTHON™, php, SQL, C, C++, JAVA®, C#, Fortran, BASIC, shell scripts, Perl, or the like.

Conditional language used herein, such as, among others, "can," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment. The terms "comprising," "including," "having," "involving," and the like are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations, and so forth. Also, the term "or" is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term "or" means one, some, or all of the elements in the list.

Disjunctive language such as the phrase "at least one of X, Y or Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to present that

an item, term, etc., may be either X, Y or Z, or any combination thereof (e.g., X, Y and/or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y or at least one of Z to each be present.

Unless otherwise explicitly stated, articles such as "a" or "an" should generally be interpreted to include one or more described items. Accordingly, phrases such as "a device configured to" are intended to include one or more recited devices. Such one or more recited devices can also be collectively configured to carry out the stated recitations. For example, "a processor configured to carry out recitations A, B and C" can include a first processor configured to carry out recitation A working in conjunction with a second processor configured to carry out recitations B and C.

While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, certain embodiments described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An apparatus to provide a view of reflected and transmitted light to create a visual effect that combines reflected images and transmitted images, the apparatus comprising:

a display configured to display images;

a mirror having a first side and a second side opposite the first side, the display facing the second side of the mirror, the mirror being partially-reflective and partially-transmissive such that at least a portion of light provided by the display passes through the mirror and is visible from the first side of the mirror;

a frame surrounding the mirror;

a plurality of projectors positioned on the frame and configured to illuminate a user and object elements facing the first side of the mirror;

a camera configured to acquire image data of the user and object elements; and

an image blending system communicably coupled to the display, the plurality of projectors, and the camera, the image blending system configured to:

in a scanning phase, analyze image data received from the camera to determine locations of the user and object elements;

in a tracking phase, analyze the image data received from the camera to determine a location of the user's eyes, the location of the user's eyes including a height and a distance of the user's eyes relative to the mirror;

control the plurality of projectors to illuminate at least some of the user and object elements such that light from the illuminated user and object elements is reflected by the mirror to form reflected light, the reflected light visible from the first side of the mirror within a first portion of the first side of the mirror; and

control the display to output display light, wherein a first portion of the display light corresponds to an image,

wherein the first portion of the display light passes from the second side of the mirror to the first side of the mirror such that the first portion of the display light is visible from the first side of the mirror within a second portion of the first side of the mirror,

wherein a second portion of the display light passes from the second side of the mirror to the first side of the mirror at a location corresponding to the first portion of the first side of the mirror, and

wherein the second portion of the display light has a light intensity lower than a light intensity of the reflected light such that the reflected light is visible instead of the second portion of the display light;

wherein at least a portion of the reflected light and the display light combine to form a composite image.

2. The apparatus of claim **1** further comprising a lighting fixture, wherein the image blending system is further configured to control the intensity of light output by the lighting fixture to enhance the composite image.

3. The apparatus of claim **1** further comprising an active transmission matrix comprising a two-dimensional array of pixels, the active transmission matrix positioned between a screen of the display and the mirror, wherein the image blending system is further configured to control the transmissive properties of the two-dimensional array of pixels of the active transmission matrix to control the display light transmitted through the mirror to improve control of a contrast between the reflected light and the display light.

4. A method of generating a combined image at a targeted location that combines reflected images and transmitted images, the method comprising:

acquiring image data of surfaces in an environment;

generating a virtual three dimensional model of the surfaces in the environment by analyzing the acquired image data;

acquiring image data of an object positioned within the environment;

identifying a target on the object by analyzing the acquired image data;

generating images that are transmitted through a mirror from a first side of the mirror to a second side of the mirror such that the images are visible to the identified target on the object from the second side of the mirror; and

projecting light onto selected surfaces in the environment to selectively illuminate the selected surfaces such that light from the illuminated selected surfaces is reflected by the mirror to form reflected light, the reflected light visible from the second side of the mirror within a first portion of the second side of the mirror,

wherein a light intensity associated with the images within the first portion of the second side of the mirror is lower than a light intensity of the reflected light such that the reflected light is visible instead of the images within the first portion of the second side of the mirror, and

wherein a combined image is visible to the identified target, the combined image comprising an image associated with the reflected light and the images transmitted through the mirror.

5. The method of claim **4**, wherein generating the virtual three dimensional model of the surfaces in the environment comprises determining distances to the surfaces.

6. The method of claim 4 further comprising modifying light within the environment to enhance the combined image.

7. The method of claim 4, wherein identifying the target on the object is performed in real time to modify the generated images and the projected light based on movements of the identified target.

8. The method of claim 4 further comprising determining for each of a plurality of projectors a pattern of light to project to selectively illuminate the selected surfaces.

9. An apparatus comprising:

a display device comprising a screen;

a planar reflective surface positioned adjacent to the screen of the display device, the planar reflective surface configured to allow transmission of light from the screen through the planar reflective surface to a viewing side of the planar reflective surface;

a plurality of projectors configured to project light onto surfaces on the viewing side of the planar reflective surface;

an image acquisition device positioned to acquire images of the surfaces on the viewing side of the planar reflective surface; and

an image blending system configured to:

receive acquired images from the image acquisition system;

control the plurality of projectors to selectively illuminate surfaces on the viewing side of the planar reflective surface such that light from the illuminated surfaces is reflected by the planar reflective surface to form reflected light; and

control the display device to illuminate a portion of the screen and to leave a portion of the screen blank such that display light corresponding to the illuminated portion of the screen passes through the planar reflective surface to the viewing side of the planar reflective surface within a first portion of the viewing side of the planar reflective surface,

wherein a light intensity of the display light is greater than a light intensity of the reflected light within the first portion of the viewing side of the planar reflective surface such that the display light is visible instead of the reflected light within the first portion of the viewing side of the planar reflective surface, and

wherein at a targeted location on the viewing side of the planar reflective surface a combined image forms, the combined image comprising the reflected light and the display light.

10. The apparatus of claim 9, wherein the plurality of projectors are adjacent to a periphery of the planar reflective surface.

11. The apparatus of claim 10, wherein the plurality of projectors includes four projectors positioned at corners of the planar reflective surface.

12. The apparatus of claim 9, wherein a surface of the screen is parallel to a surface of the planar reflective surface.

13. The apparatus of claim 9 further comprising a light source configured to vary an intensity of light output by the light source based on instructions from the image blending system.

14. The apparatus of claim 9, wherein the screen has a width that is at least 90% of the width of the planar reflective surface.

15. The apparatus of claim 9, wherein the display device is attached to the planar reflective surface.

16. The apparatus of claim 9 further comprising an active transmission matrix positioned between the screen of the display device and the planar reflective surface.

17. The apparatus of claim 9, wherein the screen is configured to output polarized light.

18. The apparatus of claim 17, wherein the screen is configured to alternately output light of orthogonal polarizations.

19. The apparatus of claim 9 further comprising a lenticular array positioned between the screen and the planar reflective surface.

20. The apparatus of claim 9, wherein the image acquisition device comprises a camera configured to detect infrared light.

* * * * *